ANNEX 1

6323-EN-01
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NINTH INTERIM REPORT

PROVISIONAL OUTLINE OF AMS MONOGRAPH.

Title: Mesoscale modeling of the atmosphere

(A review based on papers presented at the U.S. Army Atmospheric Sciences Laboratory Workshop, El Paso, Texas, 16-18 June, 1992)

Foreward: Background of workshop, modeling project, purpose of monograph, outline of contents. (RPP, RP) 4pp

Part 1 Aspects of mesoscale modeling.

1. Introduction. Comments on model formulations (Sect.14) (RP) 4pp
2. Initialisation. (Madala) 15pp
3. Sub-grid scale parametrisation. (Uliasz) 15pp
4. Terrain and surface effects. (Warner) 15pp
5. Incorporation of moisture. (Straka) 15pp
6. Radiation schemes. (Rockel,Raschke) 15pp
7. Model evaluation techniques. (Hanna) 15pp

Part 2 The mesoscale modeling comparison project.

8. Introduction. Background, requests of participants. (RPP) 4pp
9. Project WIND data. (Cionco) 6pp
10. NCAR/PSU model. Brief description and results. (Alpert) 10pp
11. FITNAH model. (Gross). 10pp
12. RAMS model. (Walko) 10pp
13. HOTMAC model. (Yamada, Henmi) 10pp
14. NORAPS model. (Dumais) 10pp
15. Comparison of model results. (Gross) 10pp

Appendix. Model Equations (RPP 8pp

Conclusions - The future. (RP) 4pp

RPP. 12 March 1993.

Coordination of Mesoscale Meteorological Research
between ASL and European Groups

Principal Investigator : Professor R. P. Pearce

Contractor : University of Reading, U.K.

Contract Number : DAJA 45-90-C-0009

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NINTH INTERIM REPORT
1st August 1992 - 31st March 1993

The two main activities undertaken during this period have been

1. Collation of the American Meteorological Society monograph

A-1

and 2. The Monterey Panel Meeting.

Also, a rescheduling of this Contract has been agreed, with this report due on 31st March, 1993 and the Final Report due 31st December 1993.

1. The A.M.S. Monograph

Some rescheduling of the timetable for producing this volume has become necessary, but in some respects this will prove beneficial.

One of the authors (Dr. Mason) has found it necessary to withdraw, but his section has been re-allocated to Dr. Uliasz. This will not be ready until the end of May 1993. Two other authors have still to produce their manuscripts, but have promised them within a week or so. In the light of these delays and the discussion at the Monterey Panel meeting, it has been proposed that two further sections be added. One of these will be an account of the NORAPS model results, should they prove satisfactory, and the other is a chapter in which a selection of the results from the models will be compared. The latter will be prepared by Dr. Gross.

The sections on the model results so far received have been reviewed in detail by Dr. White and corrected manuscripts will be available shortly. The review papers in Part I so far received have been sent to referees.

It is therefore unlikely that the complete manuscript will be ready for submission to the A.M.S. before August 1993. It will, however, be somewhat larger than originally estimated and, hopefully, include an account of the NORAPS model. The provisional amended outline is attached as **Ninth Report Annex 1**.

2. The Monterey Panel Meeting

This meeting, the first to be held in collaboration with NRL, was highly informative to the Panel and led to a most useful discussion on future BED/ARL mesomet modelling. An account of the meeting, together with its recommendations are attached as **Ninth Report Annex 2**.

Ninth Interim Report (cont'd....)

ARL agreed that, in line with these recommendations, it would arrange for work to start immediately on the testing of NORAPS using the WIND Project data.

The Panel agreed that, in order to expedite the assessment of the NORAPS system, Dr. Gross should be invited to carry out a detailed comparison of the results from the NORAPS test with those from the four models used in the Model Comparison Project. This should be carried out as a Special Project funded under the Panel contract and his assessments considered by the European members of the Panel at a meeting in Europe by mid-September, 1993. Professor Pearce would then visit ARL to report the results of the assessment and to provide the Panel's input into reaching a firm decision on the choice of operational model for the Army in FY95.

At its meeting in Europe the Panel would also consider the form of the Final Contract report and, if requested by ARL, recommend further model tests to be carried out using the WIND Project data.

Robert P. Pearce

Professor R. P. Pearce
16th March, 1993

PANEL REPORT ANNEX 2

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REPORT OF US ARMY MESOMET PANEL MEETING

Room 103, Glasgow Building

NRL, Monterey, CA.

23rd - 25th February, 1993

EXECUTIVE SUMMARY

Following the proposal of the Panel at its meeting in El Paso, 16th-18th June 1992, this further meeting was held to enable the Panel to advise ARL on future model development in collaboration with NRL. Following presentations by members of ARL and NRL modelling groups and invited technical experts, extensive discussions led to the following recommendations:

Recommendation 1:

The Panel reviewed, in detail, the new mesoscale model development strategy proposed by BE/ARL and strongly recommends the adoption of its two major components, namely

(a) to leverage the mesoscale modelling expertise of NRL under Project Reliance by adapting Navy models for service-specific applications and

(b) to work with NRL to adapt their non-hydrostatic model for Army use.

Recommendations 2 and 3 relate to the other components of the proposed strategy, i.e. the HOTMAC model, the NRL hydrostatic model and the need to satisfy the requirements of the Army Science and Technology Master Plan Science and Technology Objective by FY95.

Recommendation 2:

The Panel reviewed the mesoscale modelling situation at ASL in connection with the milestones put forward by Mr. Harris. Taking this and the manpower situation at ASL into account the Panel recommends that, following a period of, say, 3 to 4 months needed to make the HOTMAC operationally viable, it should aim to concentrate all its subsequent efforts on the implimentation of NORAPS rather than HOTMAC as the Army's operational model for FY95; this, provided that, by that time NORAPS has performed satisfactorily using the WIND data model comparison test.

Recommendation 3:

The Panel noted that the NORAPS model was not tested on the Project WIND data prior to the El Paso Workshop, and as a consequence it has not been assessed against other models (in particular, HOTMAC).

The Panel recommended that ARL should undertake runs with existing hydrostatic NORAPS using the Project WIND data in close cooperation with NRL (Dr. Rao Madala/Dr. Richard Hodur) so that the results can be included within the Monograph to be published by the A.M.S. The Panel further recommended

that the results should be distributed to a researcher nominated by the Panel who would be instructed to make an assessment of all the models run on Project WIND data for inclusion within a chapter of the Monograph. To achieve this the results from the NORAPS runs need to be available by the end of May 1993.

Recommendation 4:

The Panel points out that in order to derive the maximum benefit from the NRL meso-modelling expertise , the Army should focus more sharply on its needs and requirements and asign to them clear priorities.

Recommendation 5:

The discussion of the γ-mesoscale modelling experts showed some doubt whether, at this stage, a mesoscale (non-hydrostatic) model should be developed for Army usage or whether an existing meso-β-scale version should be used with a postprocessor which in essence is an interpolation scheme with physical constraints (e.g. non-divergent wind fields). The Panel recommends that the latter should be pursued and recommends further that this could be done by NRL.

Recommendation 6:

The Army requires the model to have various specialized capabilities. These include the ability to initialize the model from a single sounding and/or other data sources gathered locally. The Army and Navy should work closely together to ensure that the model meets all Army requirements.

Recommendation 7:

The tasks of acquiring, processing, and quality-controlling model input data, of setting up the model for a particular site, of running the model, and of producing model output should be automated as far as possible to minimize man-machine interaction. An expert system for flagging bad model input and for identifying situations where model output is not trustworthy should be developed and implemented, including access to e.g. the first hour results of a 12 hour run. It should also have a versatile graphical output system to enable forecasters to access and examine the model results in any form that they consider useful, e.g. cross sectioning and time series.

Recommendation 8:

An effort should be made to harmonise model code modules and model output to facilitate model testing and application. The use of the internationally agreed "plug compatible" conventions for meteorological modelling codes is recommended.

Recommendation 9:

Consideration must be given now to the training requirements for personnel who are to use the mesoscale forecast model in IMETS from FY95. This should include a period of practical experience in running the model and interpreting the results for a set of specific Army requirements in the field.

Recommendation 10:

The Army should strongly pursue and further develop collaboration with the other armed forces. In doing so the Army must see to that its needs and requirements are given appropriate priority. The Panel believes that with this in mind, the Army should consider development of Project Reliance into institutionalised cooperation (a joint Forces Mesoscale Modelling Centre) taking care of operational aspects as well as development of mesoscale modelling.

REPORT OF US ARMY MESOMET PANEL MEETING

Room 103, Glasgow Building

NRL, Monterey, CA

23rd - 25th February, 1993

The list of meeting attendees is attached as Annex 1 and the meeting Agenda as Annex 2.

1. <u>Introductory Remarks</u>

The meeting was opened by Mr. Gene Morris, Chief of Planning and Programs at ARL. He outlined the new administrative arrangements for ARL under Project Reliance, a collaborative arrangement between the Research Laboratories of the US Army, Navy and Air Force. As a result of this, ARL would be closely linking its mesoscale modelling efforts with that of the Navy, applying their research to Army needs.

Professor Pearce then reminded participants of the conclusion reached at the El Paso Panel meeting in June 1992 that this further meeting should be held to enable the Panel to advise on future model development at ARL in collaboration with NRL. The contract supporting the Panel had been amended to run until December 31st, 1993, to enable this meeting to take place and for it to continue to support and advise on the ARL mesomet modelling programme. In preparation for this meeting, Mr. James Harris had prepared an ARL modelling strategy document and expert comments on this had been invited from Dr. Alpert, Dr. Gross and Dr. White (see Annex 3). They, and Dr. Henmi, would be presenting their papers as the next agenda items for general comment.

Dr. Hodur then briefly described the local administrative arrangements for the meeting.

2. <u>BED Modelling Strategy</u>

Mr. Harris outlined the strategy described in his written document (see Annex 3) stressing the following points:

- An initial Target Area Met. Model, based on HOTMAC, able to run on a 76 mip type of workstation, has been scheduled to be available to the Army in FY 1995.

- An improved non-hydrostatic version, based on the Navy model, is scheduled for FY 1997.

- A Weather Test Bed System is being set-up at White Sands. This will include data reception from a Communications Satellite (COMSAT).

- Dr. John Hovermale (NRL) chairs the Environmental Sciences Panel of Project Reliance with Mr. Harris himself as a Group Operator. A close liaison between Army and Navy mesomet modelling will thus be maintained

with the Navy taking the lead. The Army will lead the data acquisition programme.

Among the points raised in the discussion was the need, based on experience at the U.K. Met. Office, to include cloud in the four-dimensional (4-D) data assimilation.

3. The present status of HOTMAC

The first aspect described by Dr. Henmi was the application of the HOTMAC model to short-range forecasting on the battlefield scale. Forecast and Analysis fields of U, V, T, $T-T_d$ and h would be received at mandatory p-levels on a 381 Km grid from the USAF Global Spectral Model (GSM) under IMETS, and incorporated into HOTMAC using a nudging procedure. Operational evaluation is planned in 3-6 months. The main points arising from the discussion concerned the use of nudging and these are included in the meeting recommendations (see Executive Summary).

The second aspect of HOTMAC described by Dr. Henmi was its use in experiments at White Sands in Computer Assisted Artillery Meteorology (CAAM). So far little or no improvement had been obtained over results using a traditional single wind and temperature sounding up to 12 Km.

4. Assessments of BED modelling strategy
(Chairman and Rapporteur : N.E. Busch)

Dr. Günter Gross presented a comparison and evaluation of model outputs versus Project Wind data with special emphasis on a comparison of his own model FITNAH - a non-hydrostatic model - with ASL's HOTMAC model, which is a hydrostatic model.

The following comments were made:

- The comparisons showed that the hydrostatic and non-hydrostatic models seem, in general, to perform equally well with the horizontal resolutions used.
- Many effects other than those stemming from hydrostatic limitations cause differences in the model outputs.
- When the horizontal resolution becomes fine enough (finer, say, than 5 Km) the models must be non-hydrostatic.
- Non-hydrostatic models can be made to run almost as fast on computers as the hydrostatic models.
- Although it may not have, in many circumstances, the highest priority to introduce non-hydrostatic computational schemes one should be aware of the fact that future model development will concentrate on non-hydrostatic models.

Dr. Pinhas Alpert noted that the Army expects to take delivery of a newly developed, non-hydrostatic model by 1997 and observed that several non-hydrostatic nested mesoscale models are in current use, (the PSV/NCAR model, the RAMS/CSU model, and the UK Met. Office model, for instance). Consequently, he questioned the Army strategy which suggests the use of ASL's model HOTMAC in the interim period until the new non-hydrostatic model is installed. He made the points that HOTMAC has not been tested in severe

weather (HOTMAC is a fair-weather model), that nesting experience with the model appears to be limited, and that the hydrostatic limitations could be problematic for Army uses.

Dr. Peter White reviewed β-mesoscale modelling in general and made the following comments:

- Running models repeatedly over the same geographical area and interpreting the results after suitable adjustment of boundaries and boundary conditions is quite different from running models which are constantly relocated.

- Interpretation of model results when backed by the resources of a major meteorological centre and working with models in the battlefield environment are two very different things.

- Army goals seem to be too vague or too many without clear relative priority, i.e. they seem not specific and categorised enough for the design of models.

- Confidence in models and model results among "customers" is important. Disappointed reaction by forecasters due to unrealistic expections and poor handling of models should be avoided; there is a danger that providing inadequately developed and validated models in the field will tend to a loss of confidence in their usefullness as a whole.

- Man-machine interaction should be minimized. Forecasters can only (safely) do simple things to models and those that are easy to automate.

Since 1986 the UK Met. Office has operated a β-scale non-hydrostatic model; since December 1992 a hydrostatic version had been used with data assimilation. Based on experience with this model Dr. White stated that

- The model does a good job for winds, models clouds poorly and fog not reliably at all.

- The UK Met. Office sets following priorities:

    1. Improvement of 4-dimensional data assimilation scheme.

    2. A better advection scheme (positive definite).

    3. A non-hydrostatic scheme.

During the discussion, the following remarks were made:

- When going from 50 Km grid size, say, to 1 Km or smaller, the model must be non-hydrostatic.

- The parameterization schemes must depend on the grid size.

- The equations and the technology are really not presenting the biggest problems when going to smaller scales. Initialisation, parameterization and input data from below (the ground surface) present much more serious problems.

5. Overview of Navy Modelling Programme
(Chairman and Rapporteur : W. Klug)

In the first session of Wednesday morning, Drs. Hodur and Madala, both from NRL, gave an extended overview on the Mesoscale modelling activities of the Navy. There is in essence one model, which exists in different versions. The first version is called NORAPS, which has a horizontal resolution of 16-100 Km and is hydrostatic. It has the capacity to nest in a ratio 1:3:9. The NORAPS-version has a built-in hydrological cycle and is applied at FNOC twice a day to 4 different localities, e.g. Mediterrean, Persian Gulf and others. The performance is judged to be acceptable. The other version, COAMPS, has a resolution of < 10 Km and is, therefore, non-hydrostatic. COAMPS is a coupled atmosphere-ocean model and is still in the research stage. It should be operational in 1997. The last version will be used to understand air-sea-land interactions, cloud and fog formation and, also, the feedback of cloud systems. Dr. Madala offered the opinion that in order to improve forecasts, it is more important to improve the input data than going from a hydrostatic to a non-hydrostatic version. This was also emphasised in the following discussion, but it was also mentioned that the non-hydrostatic version should become mandatory for scales < 2 Km. The CPU-time for the non-hydrostatic version is only by a small factor larger that that for the hydrostatic one.

It was pointed out that there was a need for the standardisation of the software for all models used by the Army, Navy and Air Force. The conventions suggested by Kalnay (AMS Bulletin) should be appl.ed.

6. Technical Discussion I: Problems of Conversion to Non-hydrostatic Formulation

Dr. White said that he thought that the technical problems involved in converting to a non-hydrostatic formulation are well documented and understood. There are choices to be made between integration techniques (split-explicit/semi-explicit), vertical co-ordinate and grid mesh structure, but the main problems in moving meso-β to meso-γ scales are in the physical parametrizations (which may need fundamental modifications) and in the more detailed surface forcing. Consequently there is no reason why a non-hydrostatic formulation should not be adopted immediately, even for a meso-β scale model (there might be some minor advantages in terms of greater model stability and an ability to use slightly longer time steps).

One fundamental question that needs to be faced is whether routine NWP is really feasible on the meso-γ scale. Under most meteorological conditions the response of a meso-γ scale model is likely to be dominated by what comes into the domain across the boundaries and by the surface forcing. Consequently it may be more realistic to regard a meso-γ model, driven from a meso-β model, as merely an elaborate means of interpolating onto a smaller scale. In such circumstances, it is necessary to consider whether a fully configured mesoscale model is really necessary - simplified sub-models (such as the Lavoie model) may be adequate. Also it may not be necessary (or, indeed, particularly useful) to insist on tying a meso-γ model closely to detailed γ-scale initial data. A diagnostic model of this sort could be applied to output from the later stages of a larger scale forecast, e.g. T+48.

Some phenomena may be predicted better by a meso-γ model than by a larger scale model because they would be explicitly represented rather than parametrized. Convection presents a particular problem. It can be

parametrized on the β-scale (grid lengths 15-20 km) but it may be necessary for a meso-γ model to use very short grid lengths (1 km or less) because with an intermediate grid length of, say, 5 km it would be difficult to decide what to parametrize and what to represent explicitly. Kuo-type parametrizations could not be used. Adjustment schemes, such as Betts/Miller, might be possible (though NRL has not had much success with these), but new methods would probably need to be developed. Suitable observational data sets do not exist for helping in the development of meso-γ scale parametrizations.

Forcing from below would not merely depend on orography, but also on surface moisture availability, vegetation etc. (evaporation and transpiration have important effects on cloud formation). A difficulty here is specifying the details of underlying surface; orography on an appropriate scale is available (though not generally available outside the military) but quantities such as soil moisture, soil type and land use are very much more difficult to specify on the γ-scale.

The Army strategy is to have a β-scale model to provide input to a γ-scale model. However, the Army has also to consider being independent of the outside world and being able to initialize from a single radiosonde. It is not interested in interactive "what-if" type facilities. One possibility put forward was that NORAPS might be used by both the Army and the Air Force. However, it was pointed out that Project Reliance merely related to inter-service research and there was no concensus on which model should be used for in-theatre prediction by the three services.

7. Technical Discussion II: Problems of Inclusion of Fog, Low Cloud and Precipitation

Dr. Walko emphasised that it was possible to envisage modelling these processes with considerable complexity, but the choice eventually made must inevitably involve compromise between speed and accuracy. However, any scheme adopted must include, at the minimum, a conservation equation for aerosol, the ice phase and the radiative effects of clouds (often crucial in prevention of fog formation at night). It would not be possible to include all of these processes, starting from scratch, by FY97. Also, they would double the computation time.

The main points made in the subsequent discussion were:

- It had been estimated that about 1 year would be required to develop the 'Nickerson' scheme for HOTMAC.
- Problems arise through the incompatability of schemes used inside the model and on the boundary.
- Unrealistic amplification of fields can arise associated with increased sophistication of the model physics.
- Experience so far in fog prediction using the UKMO model was not encouraging.
- The Army will get considerable benefit through increased model forecast accuracy from its planned data-assimilation on the battlefield scale.

8. <u>Technical Discussion III: Model Performance Assessment</u>

Dr. Alpert, in dismissing qualitative assessment of model performance as often useful, but generally inadequate, suggested several test procedures which should be applied for the models under consideration. First, to test the model code, results should be compared with known analytic solutions for the Ekman spiral, the 2-D advection of a cone profile, the Defant sea-breeze and the linearised mountain wave equations. Further tests, mainly of the model physics, should then be carried out on the Wangara data and that from other field experiments such as the Boulder down-slope winds.

Regarding model statistics, he suggested that information was often most readily digestable from scatter plots and histograms.

At a more sophisticated level, his recently proposed Factor Analysis technique should be applied to identify the relative importance of the various physical processes in the model under difference atmospheric conditions. This provides insight into which, if any, of these processes are relatively unimportant and need not be included to a high level of accuracy. Examples were shown of NCAR /PSU model results from the Mesoscale Comparison Project using the WIND Project data. In Phase I, the heating terms alone dominated; in Phase II the main forcing of the solution resulted from the interaction between the topography and heating.

In the discussion which followed it was pointed out that recent experience in comparing the performance of air pollution models (ATMOS) suggested that a variety of statistical parameters derived for these models all tended to agree in differentiating between good and bad models.

9. <u>General Discussion</u>

In the general discussion following the Technical Discussions, the proposed BED strategy was re-examined.

It was unanimously agreed that ARL should implement the NRL NORADS model as soon as possible. HOTMAC should be developed up to the stage at which it is operationally viable within IMETS, anticipated to take about three more months. But then the physics software should all be developed and tested with the aims of using NORAPS as the Army's operational model to be available in FY95. NRL's planned conversion to non-hydrostatic form should then be a quite straightforward adaption when it became available. However, there was one crucial condition to be met before this change of strategy could be finally adopted. The NORAPS model, which up to the present had been run only with a 50 Km grid size and as a hydrostatic model, should be adapted to a 5 Km grid and tested on the WIND Project data, carrying out the integrations specified for the Mesomet Model Comparison Test.

The personnel training implications of the strategy should be considered now.

The issues raised here were used by the Panel to formulate a set of draft recommendations which were put to the full meeting at the closing session. These recommendations are set out in the Executive Summary of this report.

10. <u>Closing Session</u>

Following discussion of the Panel's draft recommendations, Mr. Morris thanked all participants for their contributions to what had been a most valuable meeting, and Dr. Hovermale and Dr. Hodur for their hospitality and excellent arrangements.

ANNEX 1

US ARMY MESOMET PANEL MEETING

List of Attendees

PANEL MEMBERS

Dr. Niels E. Busch	DK Danish Institute of Technology
Prof. Werner Klug	Technische Hochschule Darmstadt, Germany
Prof. J. Neumann	Dept. of Meteorology, Uni. of Helsinki (Emeritus, The Hebrew University, Jerusalem)
Prof. Robert P. Pearce	UK University of Reading
Dr. Peter White	UK Meteorological Office

(Apologies for non-attendance were received from Dr. Pielke and Dr. Bach)

CONSULTANTS

Dr. Pinhas Alpert	Tel-Aviv University, Tel-Aviv 69978, Israel
Prof. Günter Gross	University of Hannover, Germany
Dr. Bob Walko	Colorado State University

ARL

Mr. Robert E. Dumas, Jr.	US Army Research Laboratory
Mr. James (Jim) E. Harris	US Army Research Laboratory
Mr. Teizi Henmi	US Army Research Laboratory
Mr. Gene Morris	US Army Research Laboratory
Mr. Don R. Veazey	US Army Research Laboratory

NRL

Dr. Richard Hodur	NRL Monterey, CA 93940
Dr. L. B. Hovermale	NRL Monterey, CA 93943
Dr. Rao V. Madala	NRL Washington DC

USAF

Mr. Jerry Albrecht	Dynamics Research Corp., Scott AFB, Il
Mr. Scot Heckman	Phillips Lab.-Geophysics, Hanscom AFB, MA
Mr. Darrell Lucas	Dynamics Research Corp., Scott AFB, Il

ANNEX 2

AGENDA

U.S. ARMY MESOMET PANEL MEETING
NRL, Monterey, CA

23rd - 25th February, 1993

Tuesday, 23rd February

1300 - 1330	Introductory Remarks	Mr. Morris/Prof. Pearce/Dr. Hodur
1330 - 1400	BED Modelling Strategy (IMETS, HOTMAC, Navy Models)	Mr. Harris
1405 - 1500	Present Status of HOTMAC	Dr. Henmi
1500 - 1515	**BREAK**	
1515 - 1700	Assessments of BED Modelling Strategy (Chair: Dr. Busch)	Dr. Gross/Dr. Alpert /Dr. White

Wednesday, 24th February

0830 - 1000	Overview of Navy Modelling Program (Chair: Prof. Klug)	Dr. Hodur/Dr. Madala
1000 - 1015	**BREAK**	
1015 - 1145	Technical Discussion I: Problems of Conversion to Non-Hydrostatic Formulation	Dr. White
1145 - 1300	**LUNCH**	
1300 - 1430	Technical Discussion II: Problems of Inclusion of Fog, Low Cloud Precipitation	Dr. Walko
1430 - 1530	Technical Discussion III: Model Performance Assessment	Dr. Alpert
1530 - 1545	**BREAK**	
1545 - 1700	Panel Final Report	Lead: Prof. Pearce

Thursday, 25th February

0830 - 1200	Preparation of Meeting Report and Recommendations	Panel
1200 - 1300	**LUNCH**	
1300 - 1430	Closing Remarks	Mr. Morris
1500	ARL Departs	

ANNEX 3

AMSRL-BE-W (340a) 17 Dec 92

INFORMATION PAPER

1. PURPOSE: To outline Battlefield Environment Directorate (BE), Army Research Laboratory (ARL) strategy for mesoscale model development for evaluation by the Army European Mesomet Panel in preparation for the 23-25 February 92 meeting at Monterey, CA.

2. BACKGROUND:

- BE is working to satisfy the Army Science and Technology Master Plan Science and Technology Objective (STO) III.K.3 which calls for a 12-hour target area mesoscale forecasting capability by FY95, and to provide the Integrated Meteorological System (IMETS) with a mesoscale forecast model by FY95.

- In meteorology, the mesoscale domain can range from 2,000 km (often referred to as the regional or theater scale) to 20 km, which is near the microscale. Of primary interest to the Army is an intermediate mesoscale domain of approximately 500 km which BE refers to as the battlescale.

- To achieve the milestones above and build a strategy for future development, BE has elected to leverage the mesoscale modeling expertise of the Naval Research Laboratory (NRL). NRL has established itself as a leader in numerical weather prediction with scientists such as Dr. Madala, Dr. Chang, and Dr. Sashegyi at NRL Washington, and Dr. Hovermale and Dr. Hodur at NRL Monterey.

- Under Project Reliance, the Navy will assume the lead in mesoscale model R&D while the Army and Air Force will adapt Navy models for service specific applications. In particular, the Army (BE) will pursue incorporation of improved boundary layer exchanges over land, incorporation of a higher resolution capability, and configuration of the model for operational test and evaluation.

3. CURRENT SITUATION:

- Currently the NRL operational model is a hydrostatic regional model not well suited for forecasting small scale weather features important to Army battlescale operations. However, they are working on a nonhydrostatic model that will support the smaller domain that the Army requires. Delivery to the Army is expected in FY97.

- In the interim, to satisfy STO and IMETS milestones, BE plans to adapt a hydrostatic model called HOTMAC (Higher Order Turbulence Model for Atmospheric Circulation) which was initially developed by Dr. Yamada while at Los Alamos National Labs. Although HOTMAC has hydrostatic limitations, it is fast, numerically stable, easy to use, and has detailed boundary layer physics.

- BE will work with NRL to adapt their research grade nonhydrostatic model for Army use, with BE contributing expertise in boundary layer processes and complex terrain interactions.

4. POINTS TO BE STRESSED:

- In keeping with Project Reliance:

  -- ARL (BE) will continue to use current Navy developed models.

  -- ARL (BE) will contribute to the development and use of the future nonhydrostatic Navy model.

- ARL Point of Contact is Mr. Jim Harris, BE Directorate, WSMR, DSN: 258-4207 or Comm (505) 678-4207.

Mr. Harris/258-4207

ARMY RESEARCH LABORATORY MESOSCALE MODEL DEVELOPMENT STRATEGY

I. Introduction

The Naval Research Laboratory (NRL) is presently developing a non-hydrostatic mesoscale model which is suitable for forecasting meso-β and γ scale phenomena over complex terrain. The model will be delivered to the Army in 1997. However, until the non-hydrostatic model becomes operational, HOTMAC (Higher Order Turbulence Model for Atmospheric Circulation will be used as an operational model in the US Army's IMETS (Integrated METeorological System) to make a short-range (up to 24 hours) forecast of battlescale atmospheric phenomena. The US Army is mainly concerned with meteorological conditions, spatially within the area of 500 km x 500 km x 10 km or less, and temporally within the period of 24 hours or less.

The Army Research Laboratory's (ARL) prototype IMETS is currently receiving the forecast and analysis fields of meteorological variables produced from the US Air Force Global Spectral Model (GSM) through the Automated Weather Distribution System (AWDS). In the near future, the Relocatable Window Model(RWM) output is expected to become available. The RWM is the Air Force's regional meso-α model similar to the Navy Operational Regional Atmospheric Prediction System (NORAPS). The US Army is planning to use the output of GSM (or RWM) to initialize and assimilate into HOTMAC.

HOTMAC has been used extensively at the ARL (fomerly Atmospheric Sciences Laboratory), and can simulate the evolution of locally forced circulations due to surface heating and cooling over meso-β and γ scale areas. HOTMAC is numerically stable and easy to use, and thus suitable for operational use.

In this brief note, HOTMAC and the method of operational use are described. Future ARL plans are also mentioned.

II. HOTMAC

The basic equations for HOTMAC are the conservation equations for mass, momentum, potential temperature, mixing ratio of water vapor, and turbulence kinetic energy (Yamada and Bunker, 1988).

The potential temperature equation was modified (Yamada and Bunker, 1989) so that deviation of potential temperature from that of the large-scale flow at an initial state was solved. This modification was necessary to maintain numerically stable simulations and realistic predictions of wind fields (Yamada and Bunker, 1988) when HOTMAC was applied to simulate air flows over complex terrain with an atmospheric condition of strong wind shear and temperature inversion.

HOTMAC, also referred to as a "second-moment turbulence-closure model", is based on a set of second-moment turbulence equations closed by assuming certain relationships between unknown higher order turbulence moments and the known lower-order moments. HOTMAC can be used under quite general conditions of flow and thermal stratification: methods for turbulence parameterization are more advanced than those in simple eddy viscosity models. The present model which is referred to as the Level 2.5 model (Mellor and Yamada, 1982) solves a prognostic equation only for turbulence kinetic energy and the remaining second-moment turbulence variables such as standard deviations of wind components, and heat and momentum fluxes are solved from a set of algebraic equations.

The present model assumes hydrostatic equilibrium and uses the Boussinesq approximation. Therefore, in theory, the model applications are limited to flows where the local acceleration and advection terms in the equation of vertical motion are much smaller than the acceleration due to gravity (hydrostatic equilibrium) and temperature variations in the horizontal directions are not too large (Boussinesq approximation).

Surface boundary conditions are constructed from the empirical formulas of Dyer and Hicks (1970) for nondimensional wind and temperature profiles. The temperatures in the soil layers are obtained by solutions of the heat conduction equation. Appropriate boundary conditions are the heat balance at the soil surface and specification of the soil temperature at a certain depth. The lateral boundary values are obtained by integration of the corresponding governing equations except that variations in the horizontal directions are neglected. Parameterization of tall canopy effects on wind and radiations (Yamada, 1982) is also included in HOTMAC.

The governing equations are integrated by use of the Alternating Direction Implicit method (Richtmyer and Morton, 1967). A time increment is chosen to be 90 % of the minimum value of $\Delta x_i/U_i$, where Δx_i is a grid spacing and U_i the velocity component in the i-th direction (Courant-Freidrich-Lewy criteria). In order to increase the accuracy of finite-difference approximations, mean and turbulence variables are defined at grids which are staggered in both the horizontal and vertical directions. Mean winds, temperature, and water vapor vary most with height near the surface. In order to resolve these variations without introducing an excessive computational burden, nonuniform grid spacing is used in the vertical direction.

III. Method of Operational Use

GSM (or RWM) uses normalized pressure $\sigma = p/p_s$ for a vertical coordinate. Thus, meteorological variables are calculated on

constant pressure surfaces. Model-computed values of horizontal wind components (u,v), temperature, dew-point depression and geopotential height on mandatary pressure levels are currently communicated every 12 hours to IMETS through AWDS.

Hotmac uses z*, defined in the following, for a vertical coordinate:

$$z^* = \bar{H}\frac{z-z_g}{H-z_g} \tag{1}$$

where, z* and z are the transformed and Cartesian vertical coordinate, respctively; z_g is ground elevation above sea level; and $\bar{H}$ is the material surface top of the model; and H is the corresponding height in the Cartesian coordinate. For simplicity, H is defined as

$$H=\bar{H}+z_{gmax} \tag{2}$$

where z_{gmax} is the maximum value of z_g.

Because different vertical coordinates are used in GSM (or RWM) and HOTMAC, the following two procedures have to be taken to use GSM output data for initialization of HOTMAC:

1. Horizontal interpolations of u and v, temperature, mixing ratio, and geopotential height from GSM (or RWM) grid-points to HOTMAC grid-points on constant pressure surface. Barnes' method (1964) or the bivariate interpolation method (Akima, 1978) will be used for horizontal interpolation.

2. Vertical interpolations of the variables from constant pressure to z* surfaces at HOTMAC grid-points, using a linear or cubic-spline interpolation method.

For a 12 hour forecast by HOTMAC, both the current analysis and the 12 hour forecast fields from GSM (or RWM) are analysed by the above method, and hourly data are generated by linear interpolation between two time periods.

As shown schematically in Figure 1, the model starts spin-up computation four hours before the start of forecast initiation. At one hour before the initiation of forecast computation, the first hourly analysis fields data are read in and assimilated by HOTMAC using the nudging method for one hour. After that, the

next hourly data are read in at one hour ahead of forecast time and assimilated by nudging for one hour. This process is repeated for entire 12 hour period.

For horizontal wind components, the nudging terms $C_n(U_t - U)$ and $C_n(V_t - V)$ are added, respectively to the equations of motion for the east-west and north-south components. U_t and V_t are "target" wind components for the corresponding wind components U and V, respectively. U_t and V_t are computed, as in eq.(1) and (2), from large scale winds distributions, the geostrophic wind, and assuming a horizontally homogeneous condition (Yamada and Bunker, 1989),

$$U_t = U_{obs} - \frac{f}{G}(V_{obs} - V_g) \tag{3}$$

$$V_t = Vobs + \frac{f}{G}(U_{obs} - U_g) \tag{4}$$

Here, U_{obs} and V_{obs} are observed wind components, and U_g and V_g geostrophic wind components. Thus, U_t and V_t are in general different from the corresponding large scale wind components.

For potential temperature deviation and mixing ratio, the terms $C_n(\delta\theta_{obs} - \delta\theta)$ and $C_n(q_{obs} - q)$ are added to respective equations.

VI. Output of Forecast Computation

Output of a forecast computation includes hourly files of horizontal wind components, temperature, and mixing ratios at diffent height levels. Additionally, vertical distributions of the same variables at several locations of interest are generated while the computation is in progress.

For visualization of the above files, graphic programs developed previously for the prototype IMETS will be utilized with slight modifications.

V. Improvements and Further Studies

(a). Our immediate plan is to make forecast computations over the US Southwest area of 650 km x 650 km which contains the White Sands Missile Range (WSMR) at the center of domain. Using all available observed meteorological data, forecast skill of the operational model will be evaluated. Available data will include conventional meteorological data taken at National Weather Service and military stations, WSMR surface automated meteorological sensors, and profiler data taken at the WSMR. Satellite cloud data will be also used to evaluate cloud-cover

forecast capability of the model.

(b). The output of GSM through AWDS are reported every twelve hours on grid points spaced 381 km apart on the mandatory pressure surfaces. Therefore, only a few horizontal grid points of GSM can be contained in a battlescale model domain. On the contrary, RWM computation is made on 50 NM (nautical miles) grid spacing on 16 vertcal layers (4 levels below 850 mb) (Blackwell and Lanicci, 1992). Output from this forecast is available every 3 hours for mandatory levels and every hour for boundary layer levels. The RWM is currently under improvement for operational use, and as soon as RWM outputs become available operationally, they will be used as inputs to HOTMAC.

(c). HOTMAC has a numerical scheme for nested grid(s) computation which allows interaction between a large scale and smale scale grids. However, our experience on nested grid computation has been limited (Dumais, 1992). We will examine the feasibility of nested grid computation for operational use.

(d). The present version of HOTMAC is capable of calculating three dimensional distribution of liquid water (cloud formation). However, it lacks of cloud dissipation schemes because the parameterizations of radiation (both SW and LW) heating/cooling <u>in cloud</u> are not included. Preliminary results of simulating cloud formation and dissipation using in-cloud radiation parameterization schemes developed by Hanson and Derr (1987) have been reported (Yamada and Sasamori, 1992). Incorporation of these schemes may be considered.

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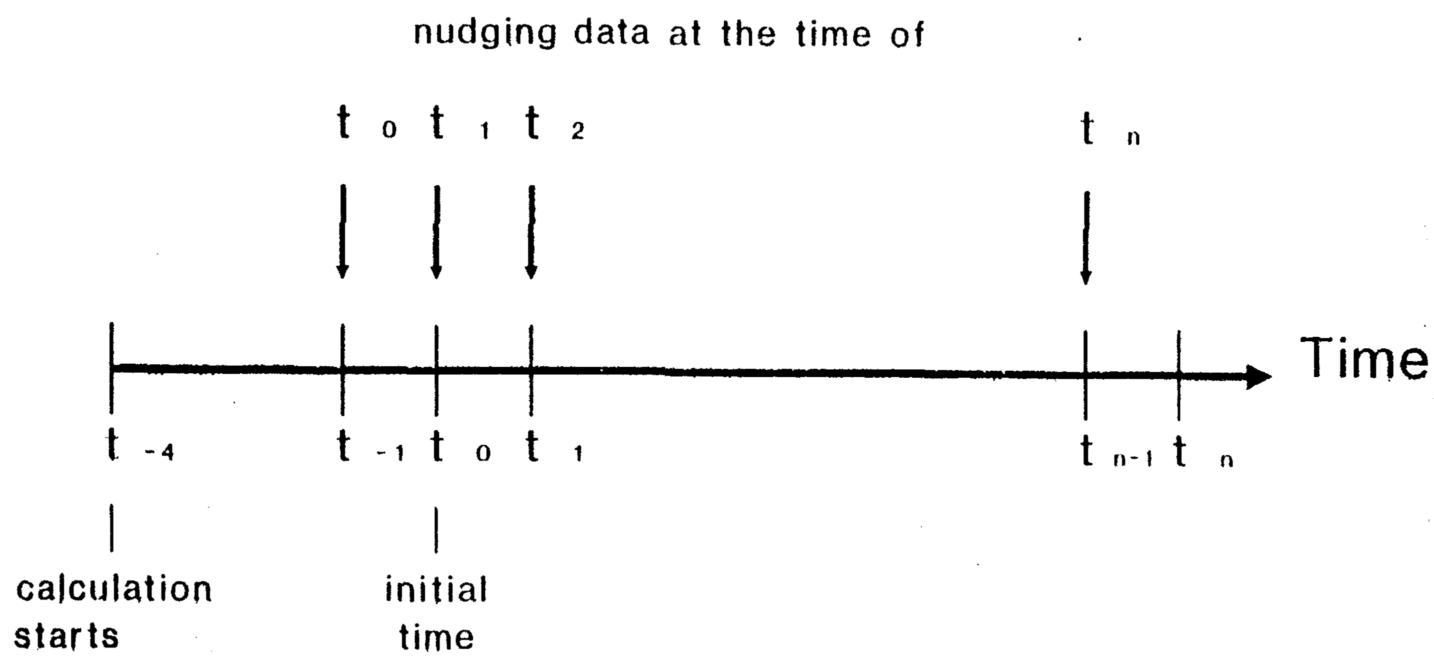
nudging data at the time of
t_0 t_1 t_2
t_n
Time
t_{-4}
t_{-1} t_0 t_1
t_{n-1} t_n
calculation starts
initial time

FIGURE 1

To: Mr. Jim Harris.ASL

cc: Prof. R.P. Pearce

2 Feb. 1993

Assessment Report for Mesoscale Modelling Strategy of ARL

By: P. Alpert. Tel-Aviv University. ISRAEL

Major Points

1. P. 1. The Info. Paper: "Delivery to the Army (of nonhydrostatic model) is expected in FY97" : At least . three existing non-hydrostatic and nesting modelling systems are in current use. First. the PSU/NCAR MM5 will be officially released within few months. Also. the RAMS/CSU system has been already tested and used. Similarly. there is the Met. Office mesoscale model. Adopting one of the available systems may make it considerably shorter for the Army to link the non-hydrostatic meso-γ scale system to the Army IMETS (Integrated Meteorological System).

2. P. 2. The Info. Paper: "In the Interim......... BE plans to adapt a hydrostatic model called HOTMAC" : Another option to be considered is to run. in the interim. the Relocateable Window Model (RWM) with higher resolution nested within the RWM with the current resolution of 50 NM(~80 km)?! Has the RWM already been tested with the higher resolution requested by the Army of ~10 km?! If this works out. it may be faster to adapt.

Additional Points on Mesoscale Model Development Strategy

1. Has the HOTMAC been applied with realistic lateral boundary conditions? On the special conditions it has been applied, situations like: severe weather, cyclone evolution, and rainfall events, are not mentioned. Such situations however are of importance for the BE and the HOTMAC development and adjustment for such cases may need more time.

2. I do not think that the Boussinesq approximation is appropriate for the variety of situations the model is intended to be applied including convective cases.

3. The 12 h pre processing period for HOTMAC may be too time consuming for Army purposes. If so, the effect of reducing this period to 1 3 h should be explored.

4. The HOTMAC nesting experience is limited (P.4 in document). The nesting capability is of particular importance for the Army. Who is going to further develop these feature?

I would like to add a comment regarding the Intercomparison Project results presented in the Workshop Volume, El Paso, May 1992: The daily net radiation in HOTMAC is consistently too low compared to observations. This refers to all stations reported, i.e. S2,S10,S11 and C3. The reason for that should be investigated. I have noticed that, along with this inconsistency, the upward long wave radiation as well as the upward solar radiation are both too high.

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Assessment to the ARL Mesoscale Modeling Strategy

(This assessment is based on the Information Paper and the Army Research Laboratory Mesoscale Model Development Strategy from Dec. 17 1992 by Jim Harris)

Situation:

NRL is developing a nonhydrostatic model, suitable to simulate the distribution of meteorological variables in complex terrain. The army is primarily interested in the socalled battlescale, i.e. in an area of 500 km x 500 km and much smaller. The army calls an operational mesoscale forecast system for the year 1995, while the nonhydrostatic model is expected to be delivered in 1997. To close the gap of two years, BE plans to use the hydrostatic model HOTMAC in the meantime.

Comments:

The hydrostatic model HOTMAC is suitable to simulate a selected spectrum of atmospheric processes and phenomena. The limitations are due to the hydrostatic approximation which allows applications only, when the local acceleration and advection in the third equation of motion (vertical) are very small. Therefore it is not possible, to simulate e.g. convection, classical lee waves or the realistic behaviour of a sea breeze front. Although it is difficult to define a sharp scale limit, from which on the hydrostatic results are not correct (e.g. Wippermann 1981, Pielke 1984), it is better (if possible) to use nonhydrostatic models because then one is always on the safer side.

Beside this more general problem, there are some other deficiencies recognizable in the HOTMAC model description mentioned above, e.g.:

- The specification of the material surface top of the model at a constant height (Eq.2) is disadvantageous. With this assumption, the simulation of e.g. the onset of a a sea breeze circulation is modelled physically not correct.

- Is it possible to consider a large scale vertical motion in the HOTMAC model? If not, this can introduce large errors in the temperature field. A large scale subsidence of 0.02 m/s in a standard atmosphere would result in a temperature increase by vertical advection of 6 K/day.

It is neccessary to discuss the reasons, summarized in the Information Paper, why HOTMAC should be used:

"Although HOTMAC has hydrostatic limitations, it is fast, numerically stable, easy to use and has detailed boundary layer physics."

- **hydrostatic limitations**
  This is true and therefore a nonhydrostatic model should be used in this scale, as it is planned in the near future.

- **it is fast**
  This is a relative statement and has to be verified for different problems by comparing the CPU time with other models.

- **numerically stable**
  This is a matter of course; a model which is numerically unstable is not a model but nonsense.

- **easy to use**
  This is true for all models; if not, it takes only a few days to make the input userfriendly.

- **detailed boundary layer physics**
  All mesoscale models have included parameterizations for detailed boundary layer physics. However, all these different schemes in these different models are worth to be discussed.

Therefore, based on the statement in the Information Paper, I cannot see the reasons for prefering the HOTMAC model.

The advantages I can see are:

- The scientists at ARL have a lot of experience in the handling of HOTMAC and not so much with other mesoscale models. This could be a strong argument for HOTMAC.
- The codes for postprocessing operations are adapted to the HOTMAC output.

The disadvantage is, and I know it is a repetition, the hydrostatic assumption.

There are other models developed, which have not this disadvantage (e.g. RAMS by R. Pielke und UKMO by P. White). Moreover, these models have a detailed cloud and precipitation scheme already included which is tested and is running routinely and therefore it would be not necessary to spend time on the inclusion of these processes in the HOTMAC model (point d of Part V).

Are there strong arguments against a time limited (till 1997) take over of one of these models (availability, copyrights, designed only for special computers, etc.)? If not, it would make sense to me to use one of the existing nonhydrostatic codes till the one of NRL is available and spend time and man power on the contributions of the army to the NRL model development (e.g. tests and selection of appropriate schemes for boundary layer processes) instead of improving a model, which will be used only for 2 years (1995-1997).

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